Improving our understanding of lead (Pb) contamination in drinking water

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Elevated Blood Lead Levels in Children Associated With the Flint Drinking Water Crisis: A Spatial Analysis of Risk and Public Health Response

Mona Hanna-Attisha, MD, MPH, Jenny LaChance, MS, Richard Casey Sadler, PhD, and Allison Champney Schnepp, MD

Objectives. We analyzed differences in pediatric elevated blood lead level incidence before and after Flint, Michigan, introduced a more corrosive water source into an aging water system without adequate corrosion control.

Methods. We reviewed blood lead levels for children younger than 5 years before (2013) and after (2015) water source change in Greater Flint, Michigan. We assessed the percentage of elevated blood lead levels in both time periods, and identified geographical locations through spatial analysis.

Results. Incidence of elevated blood lead levels increased from 2.4% to 4.9% ($P<.05$) after water source change, and neighborhoods with the highest water lead levels experienced a 6.6% increase. No significant change was seen outside the city. Geospatial analysis identified disadvantaged neighborhoods as having the greatest elevated blood lead level increases and informed response prioritization during the now-declared public health emergency.

Conclusions. The percentage of children with elevated blood lead levels increased after water source change, particularly in socioeconomically disadvantaged neighborhoods. Water is a growing source of childhood lead exposure because of aging infrastructure. (*Am J Public Health.* Published online ahead of print December 21, 2015:e1–e8. doi:10.2105/AJPH.2015.303003)

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Elevated Blood Lead in Young Children Due to Lead-Contaminated Drinking Water: Washington, DC, 2001–2004

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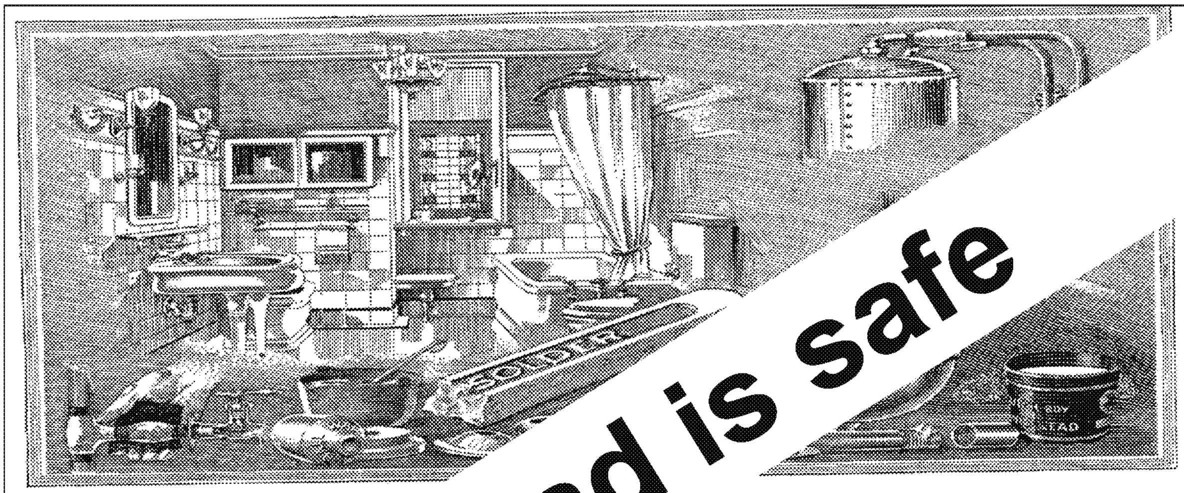
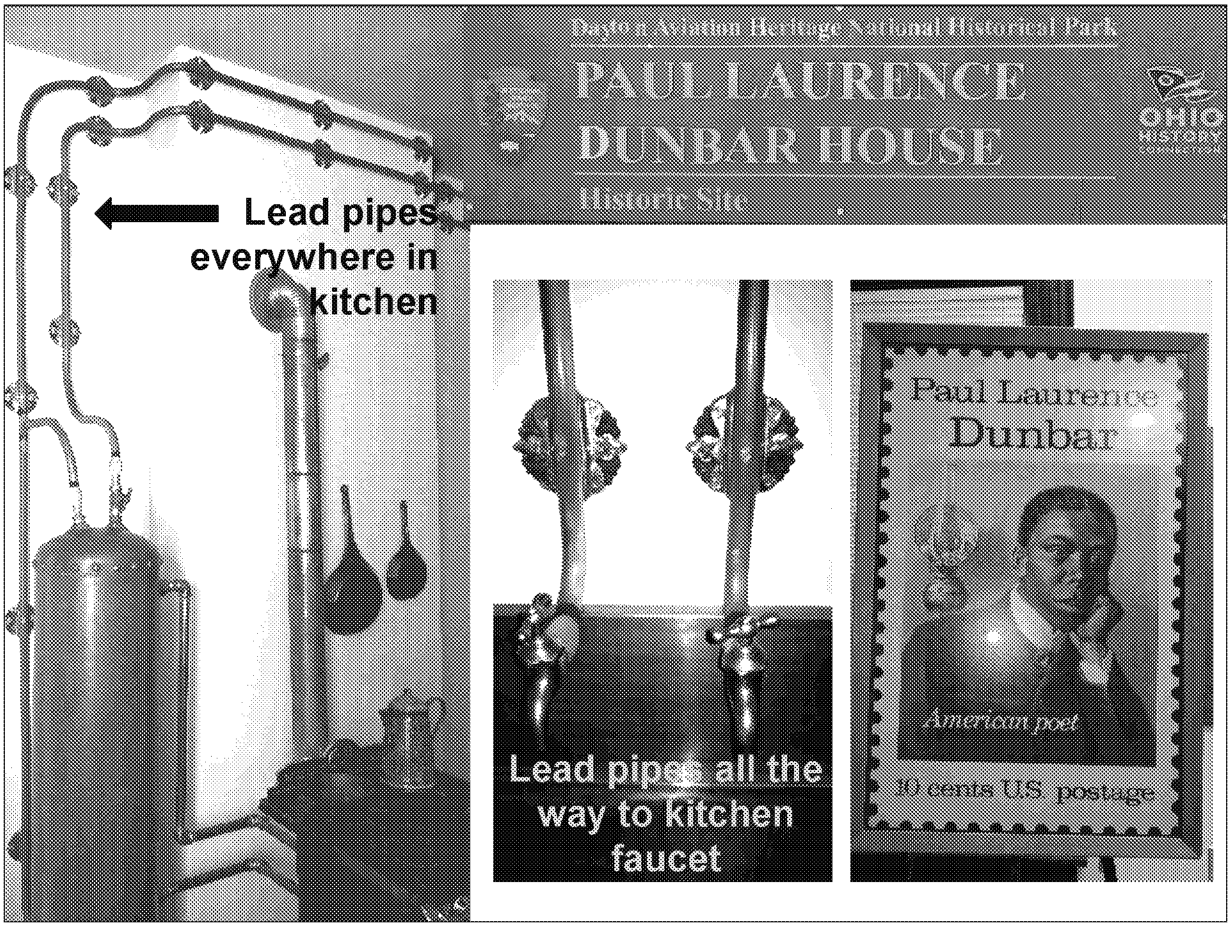
Incidence of EBL (blood lead ≥ 10 μg/dL) for children aged
≤1.3 years in Washington, DC increased more than 4 times
comparing 2001–2003 when lead in water was high versus 20
when lead in water was low. The incidence of EBL was
highly correlated ($R^2 = 0.81$) to 90th percentile lead in water
lead levels (WLLs) from 2000 to 2007 for children aged ≤1.3 year
The risk of exposure to high water lead levels varied markedl
in different neighborhoods of the city. For children aged
≤30 months there were not strong correlations between WL
and EBL, when analyzed for the city as a whole. However,
the incidence of EBL increased 2.4 times in high-risk
neighborhoods, increased 1.12 times in moderate-risk
neighborhoods, and decreased in low-risk neighborhoods
comparing 2003 to 2000. The incidence of EBL for children ag
≤30 months also deviated from national trends in a manner
that was highly correlated with 90th percentile lead in water
levels from 2000 to 2007 ($R^2 = 0.83$) in the high-risk neighborhood
These effects are consistent with predictions based on
biokinetic models and prior research.



Ad in National Geographic, 1923


Dayton Aviation Heritage National Historical Park
PAUL LAURENCE DUNBAR HOUSE
Historic Site
OHIO HISTORY
Lead pipes everywhere in kitchen
Lead pipes all the way to kitchen faucet
Paul Laurence Dunbar
American poet
10 cents U.S. postage

1904-1906

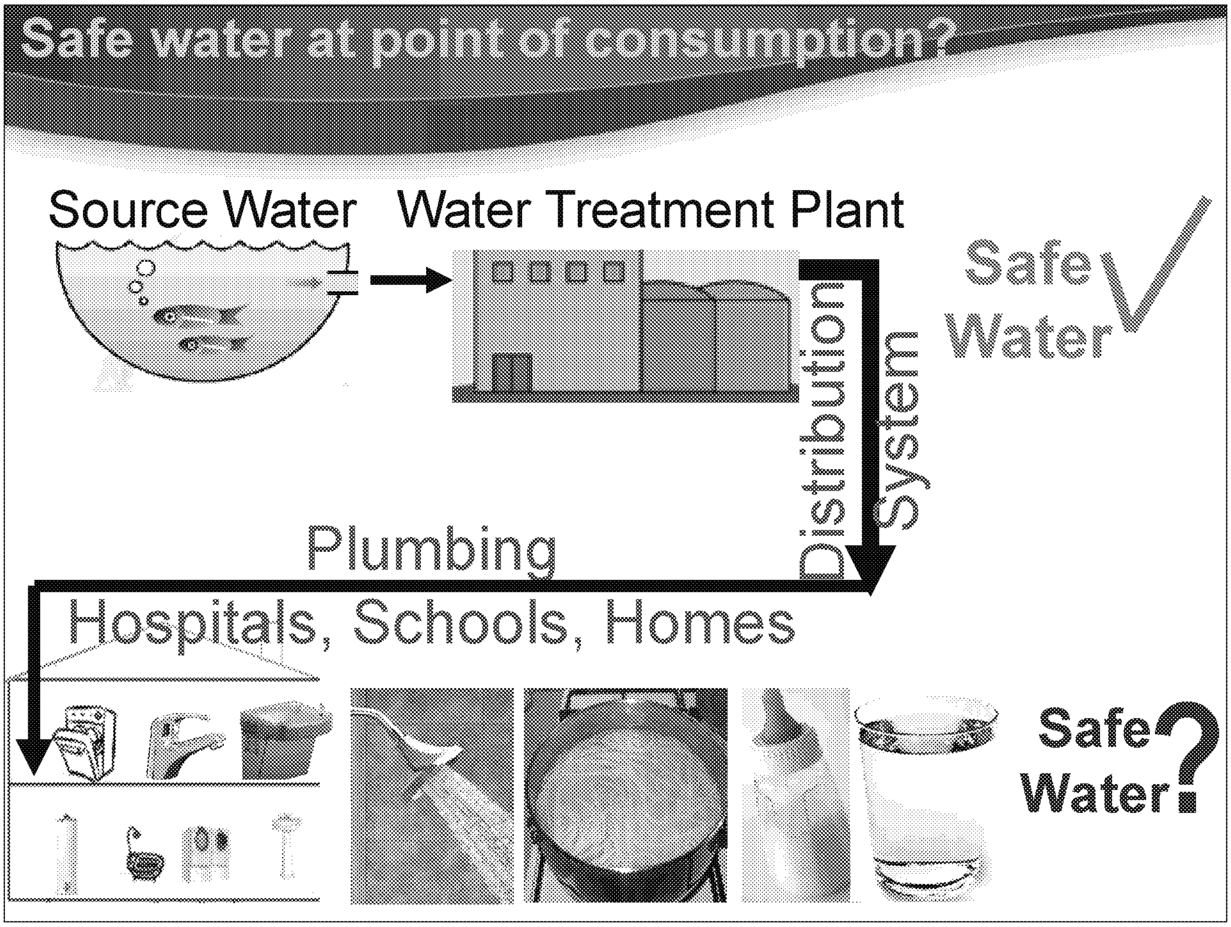
1980s

Study	Reference	Correlation between water lead (WLL) & blood lead (BLL)
Scotland	Moore et al., 1977	R = 0.52
Greater Boston	Worth et al., 1981	19% of variance explained
Ayr, Scotland	Sherlock et al., 1984 Moore et al., 1985	R^2=0.65
Wales	Elwood et al., 1984	38% of variance explained
Scotland	Lacey et al., 1985	R = 0.57
Vosgian Mountains, France	Bonnefoy et al., 1985	Spearman's rho =0.30 for men =0.47 for women
Edinburgh	Raab et al., 1987	43% of variance explained
Hawaii	Maes et al., 1991	77% of variance explained

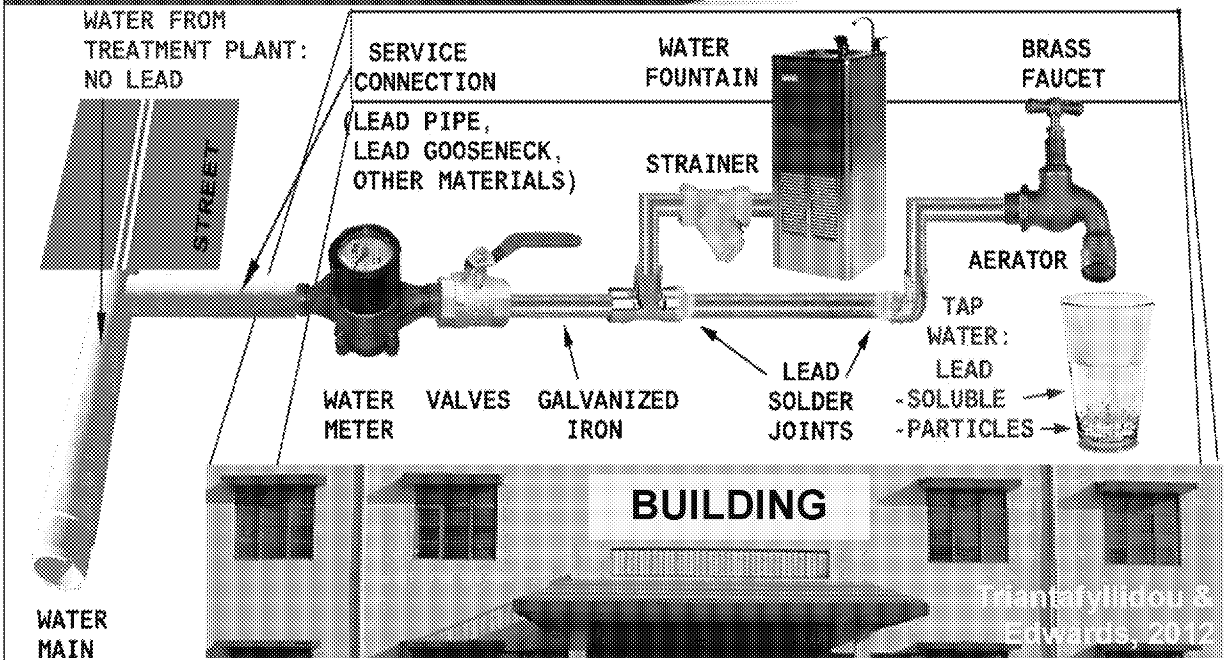
1990s to today

Study	Reference	Key Points
Saxonia, Germany	Englert et al., 1994	WLL avoidable surplus exposure
Glasgow, Scotland	Watt et al., 1996	WLL > 10 µg/L still health problem, especially for bottle-fed infants
Rochester, NY	Lanphear et al., 2002	Dust main lead exposure source, WLL also associated with BLL
Hamburg, Germany	Fertmann et al., 2004	WLL greater concern than lead paint, due to lead pipes
Washington, DC	Edwards et al., 2009	Children's EBL incidence higher in high-risk neighborhoods
Washington, DC	CDC, 2010	Lead service lines risk factor for EBL even if LCR Pb action level met
Flint, MI	Hanna-Attisha et al., 2015	Children's EBL incidence higher after change in water source

Children or women

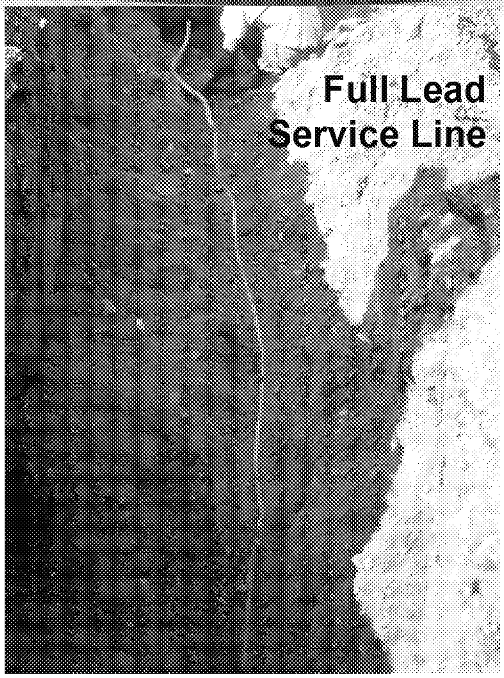

Safe water at point of consumption?
Source Water
Water Treatment Plant
Safe Water
Distribution System
Plumbing
Hospitals, Schools, Homes
Safe Water?

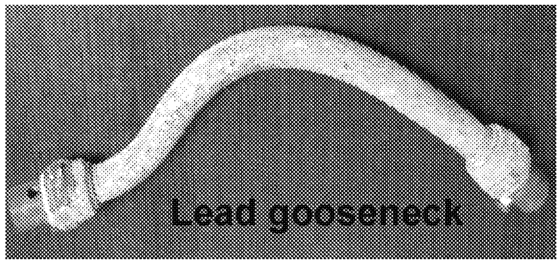
Lead Plumbing Sources



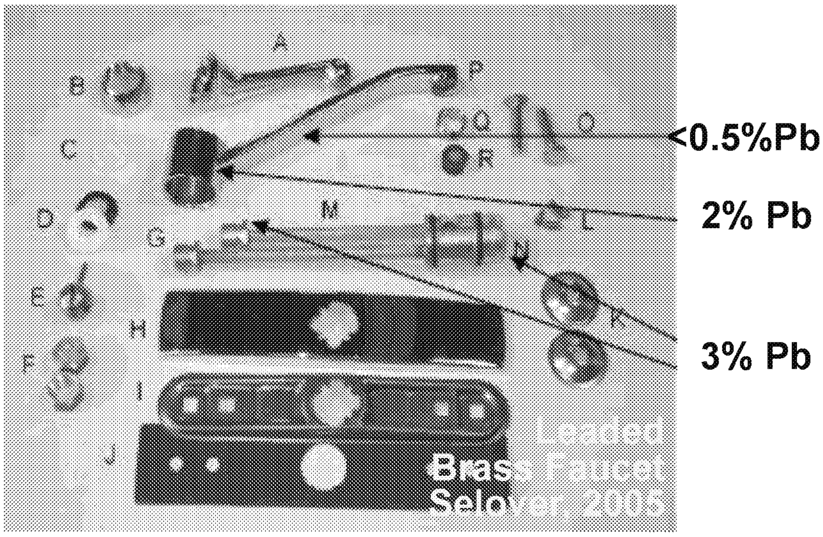
- Lead Service Lines (LSLs)
- Lead Goosenecks
- Leaded Solder
- Leaded Brass (valves, fittings, faucets, water fountains)
- Galvanized Iron Pipe downstream of leaded plumbing

Lead Plumbing Sources



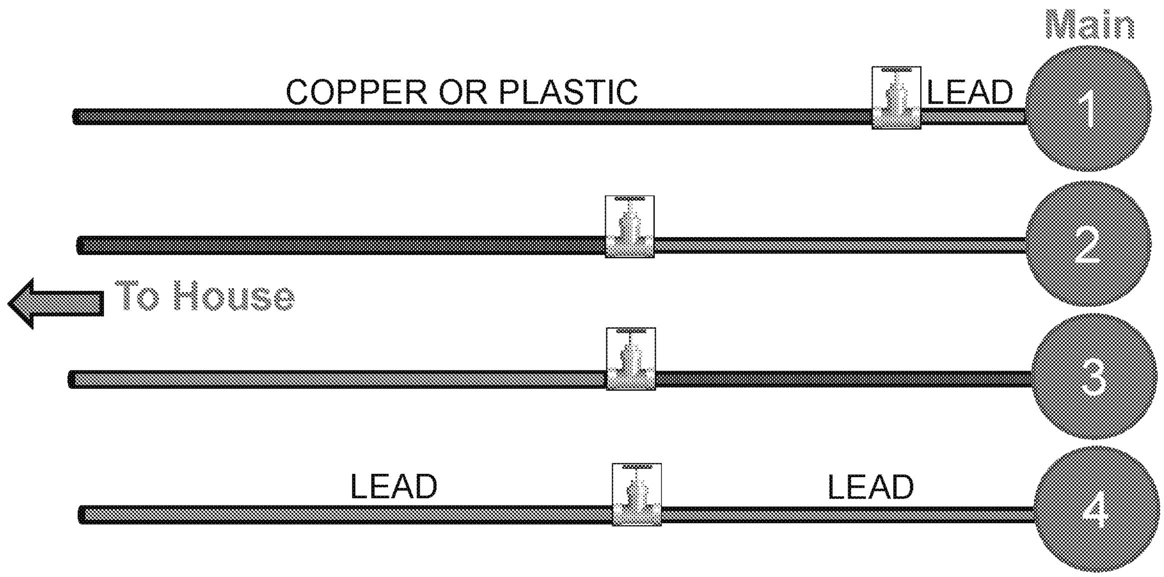


Lead Plumbing Sources



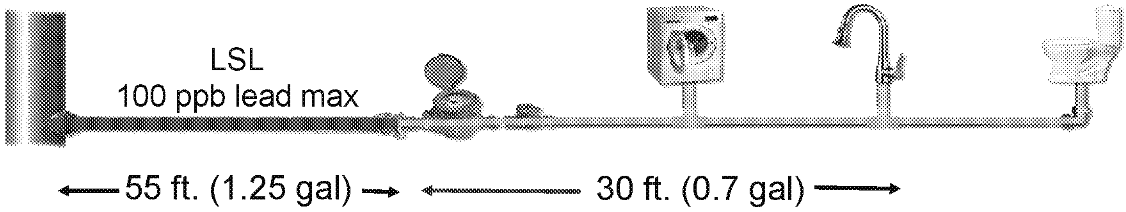
* Shut-off valves are frequently captured in 250 mL to 1 L samples

Lead sources are not uniformly distributed



Configuration #4: long run of LEAD, potentially highest exposure risk

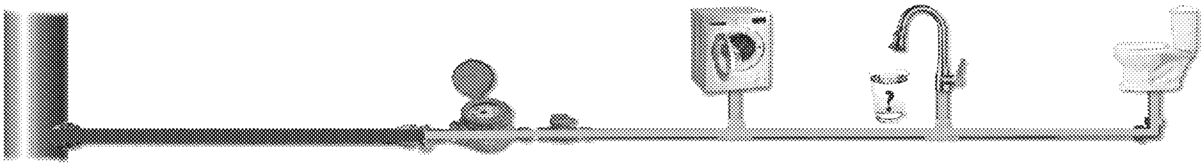
Water use patterns affect lead release



- EPANET simple home model from EPA modeling team
- Only assumes LSL, no other source of lead
- When water sits stagnant in LSL, the concentration of lead increases until it reaches solubility limit
- When water is used, the slug of lead moves from the LSL into the other pipes and eventually reaches faucets/fixtures

Murray, 2017

Water use patterns affect lead release



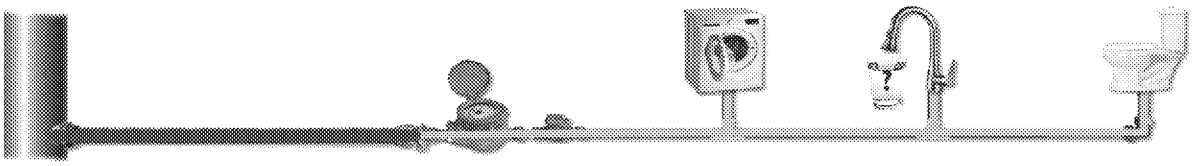
- Large water volume flushes out lead
- Defines lead concentration in the next glass of water from the tap

Water use	% LSL vol. removed	Conc. in next glass
Shower (17.2 gal @ 2 gpm)	100%	4 ppb
Toilet (1.3 gal @ 2 gpm)	50%	100 ppb

Note: For illustrative purposes only. Different assumptions would yield different modeling results.

Murray, 2017

Water use patterns affect lead release



- Small water volume moves lead from LSL into home plumbing pipes
- Concentration at tap remains 0 (no other source of lead assumed), until more water is used and slug reaches tap

Water use	% LSL vol. removed	Conc. in next glass
Glass of water (8 oz)	0%	0 ppb
Brush teeth (1 gal)	20%	100 ppb

Murray, 2017

Note: For illustrative purposes only. Different assumptions would yield different modeling results.

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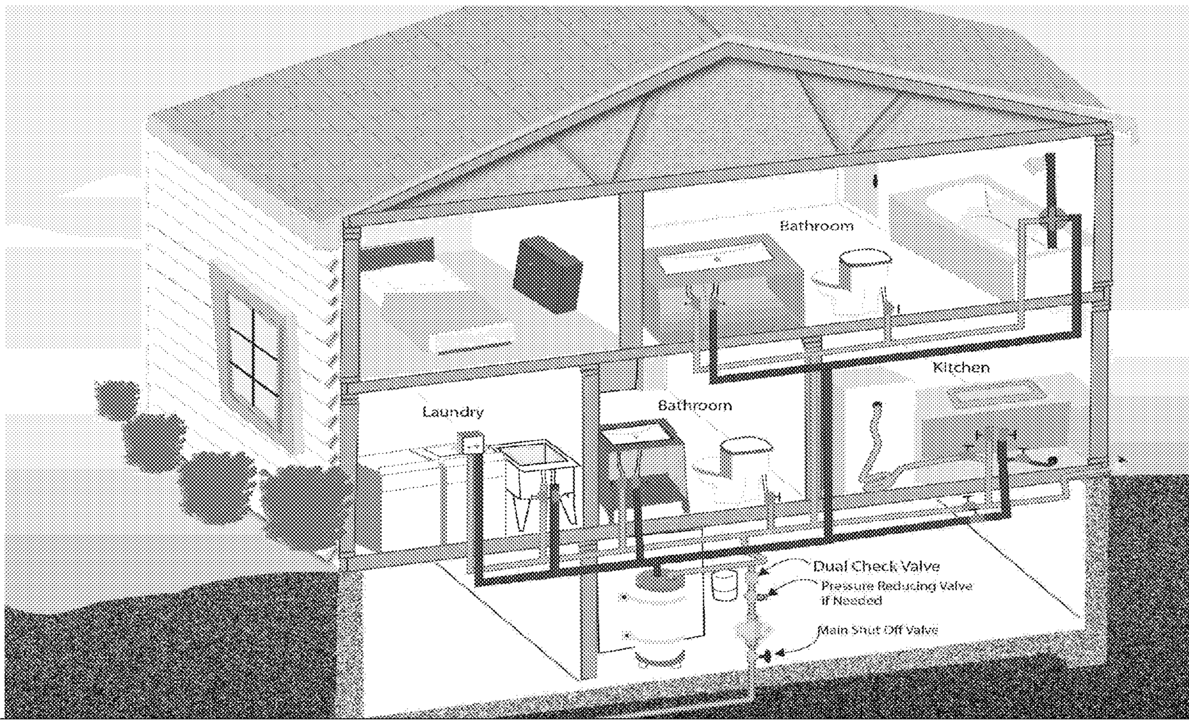
Household water use is very complex



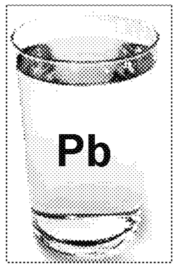
What is a "representative" water sample?

Factors affecting Pb release

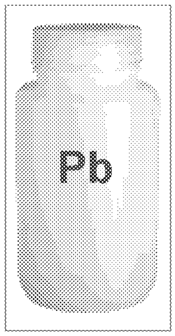
- Pb plumbing materials, dimensions, configurations & age
- Water chemistry (corrosivity) and chemical changes
- Hydraulics and hydraulic changes
- Individual water use patterns

Contribute to Pb variability

- Pb Spatial variability
- Pb Temporal variability
- Particulate vs dissolved Pb



water consumed



water sampled

Sampling: What question(s) are you trying to answer?

- No single universally applicable sampling approach for lead in drinking water exists
- There are many protocols, but each has a specific use answering a specific question
- What question(s) are you trying to answer?

Sampling: What question(s) are you trying to answer?

QUESTION(S):

SAMPLE FOR:

- Does the water meet regulatory standards for Pb?
- How effective is the current corrosion control treatment for interior plumbing?

→ 1. Lead regulatory compliance

- Where is the Pb coming from?
- What type of Pb is present (dissolved/ particulate)?

→ 2. Lead plumbing sources determination or Lead type identification

- What is the general public's exposure to Pb in water in this residence/ neighborhood/ town/distribution system?

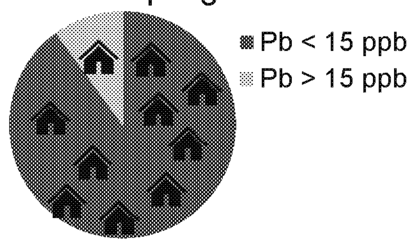
→ 3. Lead exposure assessment

1. Corrosion Control Assessment

Lead and Copper Rule (LCR), 1991

- LCR sampling pool consists of homes believed to contain major lead plumbing sources
- Homeowners collect 1 L of water from kitchen tap after overnight water stagnation (6+ hr)
- 90^{th} %ile lead results compared to Lead Action Level of 15 ug/L
- 90^{th} %ile action level is a trigger for corrosion control treatment rather than an exposure level
- Rule identifies system-wide problems rather than problems at individual buildings

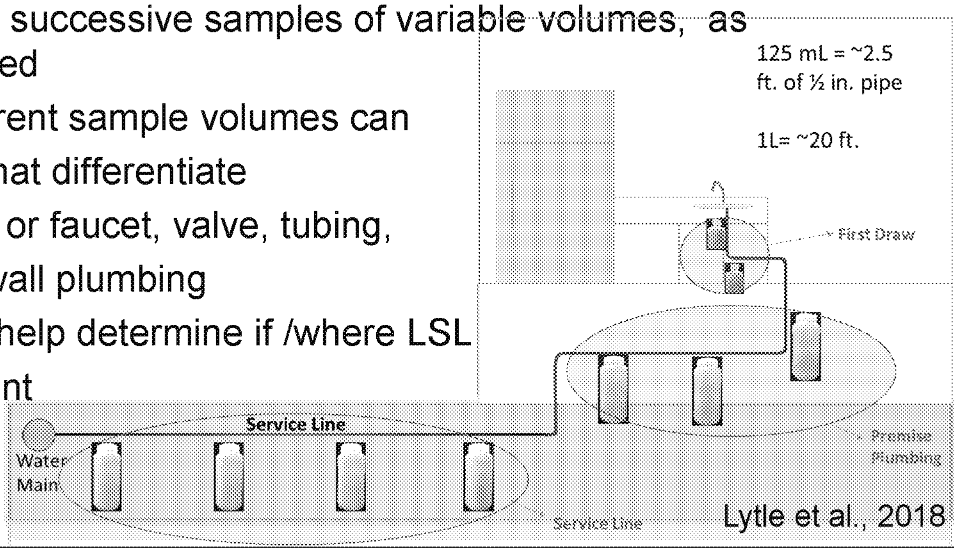
LCR Sampling Pool



2. Lead plumbing sources determination

Sequential Sampling (Profile Sampling)

- Map interior plumbing and approximate exterior route to main in terms of lengths, ID and visible materials
- Allow water to sit motionless for 30 minutes to overnight
- Take successive samples of variable volumes, as desired
- Different sample volumes can somewhat differentiate bubbler or faucet, valve, tubing, inside-wall plumbing
- Can help determine if /where LSL is present

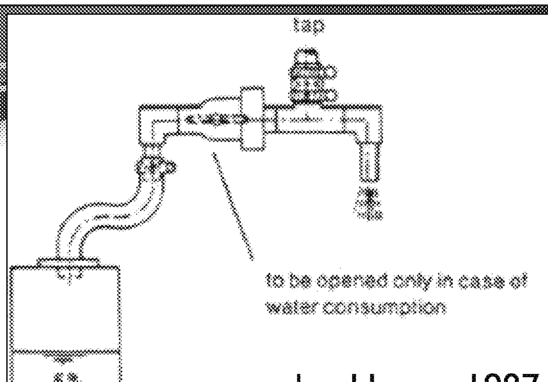


Lytle et al., 2018

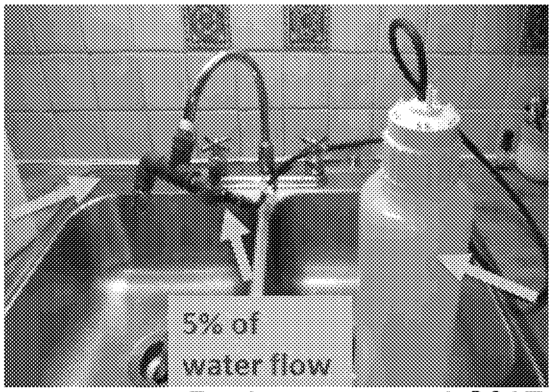
Relate Pb and/or Zn, Cu, Sn, Fe in samples to plumbing volumes/distance from tap and location of leaded materials

3. Exposure assessment

- Side Stream (Proportional) Composite Sampler
- Exposure reference method
- Device affixed to tap & consumer-operated
- Proportion of every draw meant for consumption routed into holding tank
- Collects lead under normal use conditions
- Capturing a range of flow rates, stagnation times, flow durations, and temperatures
- After one week the composite sample analyzed for lead to obtain the average lead concentration



van den Hoven, 1987

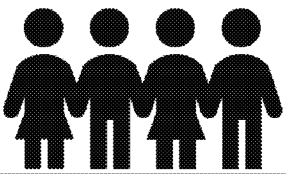


Deshommes et al, 2017

3. Exposure assessment

Environmental assessments of lead-poisoned children by Health Departments:

- Is water tested?
- If yes, what is the sampling protocol?



Lead may affect different children differently

- Example: 0-1 year old consuming reconstituted baby formula
- *IEUBK model predictions*
- *800 mL/day, Average consumption*
- *Default exposures from other lead sources*
- *GSD = 1.45 µg/dL (EPA 2004 for formula-fed children)*

BLL Threshold (µg/dL)	Predicted Water Lead Required to Exceed BLL Threshold for		
	50%th Percentile	*75%th Percentile*	*95%th Percentile*
10	60 µg/L	40 µg/L	22 µg/L
5	18 µg/L	11 µg/L	4 µg/L

Triantafyllidou et al., 2014

Summary

- Lead in water can be highly variable (spatially and temporally)
- Elevated lead in tap water can still contribute or even cause elevated lead in blood of children, in cases of sub-optimal corrosion control at the presence of leaded plumbing
- Different sampling protocols may yield different lead concentrations and sample different sources/forms of lead
- Choosing the appropriate protocol for the sampling intent is crucial to producing meaningful lead data
- Modeling suggests that the most sensitive children (i.e., upper tail of the blood lead distribution) and most exposed children (i.e., formula-fed children consuming high water volumes) are at highest risk of blood lead elevations

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Notice